A Review of New Multilateral Technology at the Rocky Mountain Oilfield Testing Center

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Abstract

This paper reviews the multilateral drilling and completion technology that is being tested at the Rocky Mountain Oilfield Testing Center (RMOTC). It also describes RMOTC and its role in bringing new multilateral well technology to the marketplace. Summary test results are presented for tests that have been partially funded by the U.S. Department of Energy.

Halliburton's open hole window squeeze presents a technique for abandoning an open hole lateral from a cased wellbore while maintaining use of the cased hole bore. Their hollow whipstock allows a lateral to be drilled and produced with the same whipstock, and full bore access allowed to both the parent and lateral bores. Their TRACS^{TM} Adjustable Stabilizer provides inclination control downhole while drilling without having to trip for a change in the bottom hole assembly. The Bottom Hole Kickoff Assembly provides a competent kickoff plug on the first try, without cement contamination problems or worry about the plug falling downhole.

Smith Drilling and Completions is now marketing the Trackmaster^{TM} Single Trip Sidetracking System. This tool allows the operator to orient and set a whipstock, shear-off and mill the entire window on the same trip. Their Rotary Steerable Stabiliser enables the bit to be steered along a preprogrammed trajectory with automatically controlled stabilizer adjustments.

International Drilling Systems, Anadrill Schlumberger, and Carrico Products and Services Company are working on the RapidConnect^{TM} system which incorporates an articulated, sealed outlet for multilateral drilling applications.

Introduction

The Rocky Mountain Oilfield Testing Center is a U. S. Department of Energy (DOE) facility that uses the Teapot Dome Field, or Naval Petroleum Reserve #3, as a testing center to help develop oil field and related environmental technology for commercial use'. It is operated by Fluor Daniel (NPOSR), Inc. under a management and operating contract for the DOE's Office of Naval Petroleum and Oil Shales in Colorado, Utah, and Wyoming. Access to an active oil field with complete production, injection and EOR facilities is provided in accordance with DOE's "Domestic Natural Gas and Oil Initiative" which allows "new applications that lead to increased production, lower operating costs, and improved environmental compliance costs to be tested at Naval Petroleum Reserve No. 3". RMOTC's mission is to support and strengthen the domestic oil and gas industry by allowing testing by individual inventors and commercial companies to evaluate their products and technology.

RMOTC's office is located in Casper, Wyoming. The field site is 35 miles north of Casper. The 9,500 acre field is 100% federally owned. There are over 1,300 wells in the field, with nearly 600 active producing wells. Well depths range from a few hundred feet to nearly 6,000 feet

Teapot Dome lies just to the southeast of the larger Salt Creek anticlinal structure. The field was originally developed in the early part of the century and became well known through the Teapot Dome scandal of the 1920's. After the oil crisis of the 1970's, full scale development of the field was authorized. During the late 1970's and early 1980's, hundreds of new producing and injection wells were drilled for primary and secondary recovery. In addition, a large-scale light oil steam drive was developed in the shallow, naturally fractured Shannon formation in the late 1980's to supplement the low primary recovery of 5% of the original oil-in-place.

RMOTC offers production and injection wells for tests. In some cases abandoned wells are also used. New wells can be drilled and dedicated to the testing of specific technologies, such as multilateral and horizontal applications. RMOTC has two drilling rigs and three workover rigs available for testing purposes. These rigs are complemented by a heavy equipment shop with mechanics, roustabouts, welders, pump shop, warehouse, water truck, winch truck, circulating unit, power swivel, chemical truck, hot oil track, etc.

RMOTC partners with industry organizations as well as individual inventors to field test new ideas, tools, procedures, and equipment. Test results am used as input for further refinements, or published to benefit the industry at-large. Confidential testing is available for proprietary technology. Clients desiring confidential testing must pay for 100% of the cost of testing, and results need not be published. Cost sharing is available from RMOTC and is based on the value of the test to RMOTC's operation. In some cases where the testing will result in a significant new oil production stream RMOTC may provide up to 50% of the cost of the test.

RMOTC also has the mission to transfer technology to the industry. Except in the case of a confidential test, completed tests are documented in a report. These test reports are listed on the Internet Home Page and are available to the public. The more notable tests are published in Society of Petroleum Engineers papers or in industry trade journals. Many of the tests are reported in industry conferences. Other tests are published internally and made available to the public on request. RMOTC's technology transfer often aids the marketing efforts of its clients by providing a credible third party opinion on its performance in a real oil field environment.

Expertise is available to RMOTC's clients for planning the tests, procuring the necessary services and materials, conducting the tests, and documenting the results. RMOTC has skilled project managers, petroleum and environmental engineers, geologists, accountants, pumpers, electricians, roughnecks, roustabouts, and equipment operators to accomplish these tasks. RMOTC has the use of the Teapot Dome field, its wells, production facilities, gas compressors, low temperature separation NGL extraction plant, water softening plant, steam generators, water disposal facilities, biotreatment facility, welding shop, pump shop, heavy equipment shop, etc. for conducting tests of oil field and environmental technologies.

Funding for RMOTC projects comes primarily from the U. S. Department of Energy and its testing clients. There is also funding provided by the State of Wyoming, and the DOE's Energy Related Inventions Program.

Multilateral-Related Projects
Halliburton's Open Hole Window Squeeze

As multilateral well technology begins to mature, more frequent requirements to abandon individual well bores will materialize. RMOTC has experienced this need in the process of testing new multilateral technology. In cooperation with Halliburton Energy Services, RMOTC has developed a [2] procedure that has proven to be effective in this operation .

A volume calculation is made for the cement plug using a large excess volume of 150% or more. A simple Class G cement slurry with minimal additives is recommended. The slurry should give sufficient pump time to get it in place, but set up quickly to prevent Rayleigh-Taylor gravitational instability from contaminating the slurry. The slurry should build high early compressive strength so the main wellbore can be drilled out without compromising the squeeze integrity. Laboratory work must be done on the slurry so that its critical properties are known at reservoir conditions. The squeeze procedure is as follows:

1. Breakdown the open hole lateral bore with mud and monitor breakdown pressures.

2. Establish an injection rate into the open hole.

3. Circulate a balanced plug in place across the window, taking precautions to prevent mud contamination of the cement.

4. Pull up above the plug and reverse out excess cement.

5. Use a hesitation squeeze procedure and build a final squeeze pressure higher than the breakdown pressure.

6. Wait on cement to build 1,500 psi compressive strength and drill out and test to a minimum required pressure.

This procedure was developed by RMOTC in partnership with Halliburton Energy Services during a Halliburton multilateral test. The plug was drilled out and tested to 800 psi. Integrity was maintained through subsequent drilling, including four round trips and setting and cementing a liner over the exit.

Halliburton's Multilateral System Using Weatherford's Designed Hollow Whipstock

The challenge with multilateral drilling and completion is to reestablish fullbore communication with the parent wellbore and obtain an isolated junction after completing the laterals'. A conventional whipstock can be used to cut the window and drill the lateral, but does not allow production from the parent wellbore. Therefore, it must be retrieved and replaced with a hollow whipstock.

A hollow whipstock has been developed by Halliburton and Weatherford that can be used for milling the window. drilling the lateral, and commingling production from both wellbores4. This system requires only running a single hollow whipstock and eliminates the need for the solid whipstock. Eliminating the requirement to retrieve the solid whipstock in a drilling environment removes this potentially high risk operation. Also eliminating the whipstock exchange reduces rig time. The lower risk and reduced rig time result in significant cost savings.

The hollow whipstock was redesigned to allow it to accomplish both the drilling and production functions. It has a steel body and hollow core. The steel body provides a rail for the mills and bits to ride as they progress through the window. The hollow core contains a soft composite material that allows for a conduit, to facilitate the packer setting process. In addition the filler material can easily be drilled out to reestablish the parent well bore. A block is located near the top of the whipstock to prevent the soft composite from being milled while initiating the window milling procedure.

The running assembly consists of a running tool, the hollow whipstock, anchor latch, multilateral packer, and orientation nipple. The running tool utilizes a shear bolt to convey the packer and whipstock assembly. The anchor latch features a mechanism to kick-over the whipstock to secure the tool against the casing wall. Should the whipstock require replacement the multilateral packer remain in place and provides for proper re-alignment. The packer holds the assembly in place during the window milling and drilling operations. The packer features an orientation nipple in the lower portion of the assembly that has a recessed helical groove which leads to a key slot aligned with the face of the whipstock. The orientation nipple is used to position and align a full bore diverter for future lateral access. A packer plug is located in the bottom of the packer assembly above the orientation nipple. Once the packer is set, this plug isolates the lower well bore to simplify well control issues during drilling of the lateral.

A gamma my logging tool is used to get the assembly on depth. A survey tool is then used to orient the whipstock. An orientation of slightly left of high side was used during the RMOTC test, When the whipstock was correctly positioned, the drillpipe was pressured up and the annulus was pressured to set the packer. The survey tool was run again to verify the whipstock position. Then the running tool was sheared off the assembly and retrieved.

Three mill runs were used to start the window, cut the window, and dress the window. A stiffer BHA is used on the final run to keep the mills from prematurely leaving the face of the whipstock. The window mill was not effective in drilling rathole below the window, so a rock bit was tripped into the hole to drill the first 30 feet, using a packed hole assembly. The hole was blown dry with air and downhole video was run to inspect the whipstock and window installation.

Several BHA's were run across the 9-5/8" whipstock and through the 8-1/2" window to check for any irregularities. These consisted of a packed hole assembly with a hole opener, a completion assembly with two screens and an external casing packer, a PDC bit assembly, and a fishing assembly with an overshot. The whipstock was then retrieved and inspected. It was found to be in excellent condition.

A 7" hollow whipstock was also run. The window was successfully completed and a 4-1/2" liner cemented in place with special impact-resistant sealant cement. The liner was heavily centralized across the window area.

A mill guide was then set inside the 4-1/2" liner and the liner and hollow whipstock were milled with a 3.875" mill to reestablish full bore communication with the parent well. Difficulties encountered with this operation necessitated changes in geometry and procedure.

The changes in the geometry and procedures identified as a result of the RMOTC testing necessitated an additional test in a simulated well test at the Halliburton Test Facility in Duncan, Oklahoma. This testing of modifications was successful and the 7" hollow whipstock and associated system Are field ready.

The hollow whipstock testing at RMOTC for both the 9 5/8" and 7" sizes provided a low risk environment to perform actual field application of new technology and resulted in design improvements, more efficient field procedures, and training for service company personnel. This culminated in the world's first completely successful subsea 9-5/8" by 7" multilateral well with reentry access. This was conducted for Norsk Hydro in the Troll Field offshore Norway.

The successful field testing of this new technology opens new possibilities for the application of economic multilateral completions. It reduces both the risk and cost of such completions and thus allows the development of reserves once thought to be marginally economic.

Halliburton's TRACS^{TM} Adjustable Stabilizer
Stabilizers are used to control inclination while drilling.

When changes in the inclination are required, the BHA is pulled and the stabilizer configuration is changed. New developments in stabilizer technology now allow the stabilizer to be adjusted from the surface, saving the cost of a trip.

Halliburton's Telemetry Regulated Angle Control System (TRACS^{TM}) stabilizer allows the blade diameter to be adjusted through timed mud flow sequences. The blades retract when the pumps are off. A control piston controls the blade position. The control piston is positioned by a solenoid valve actuated by a microprocessor that interprets signals from the surface. The position of the stabilizer can be Verified in real time with mud pulse telemetry.

The adjustable stabilizer can be used in both rotary drilling and downhole Steerable motor drilling applications. Software has been developed that can predict the response for a given BHA.

The design of the TRACS^{TM} tool is described by Underwood and Odell5. It was designed to:

- provide inclination control without BHA changes,
- continuous rotation to provide improved hole cleaning,
- optimize weight-on-bit (WOB)/rate of penetration (ROP) and inclination control simultaneously,
- maxinuze ROP by fine tuning rotary mode tendency of Steerable systems,
- reducing torque and drag through fine tuning rotary mode tendency,
- inclination control when sliding is no longer possible.

The TRACS^{TM} tool has been commercial since October, 1994. It was tested in the laboratory prior to being field tested. It underwent fatigue testing, side force testing, flow loop testing, and control module testing.

The TRACS adjustable stabilizer blades are actuated using the pressure drop across the bit and motor (if present) The purpose of the RMOTC test was to confirm that recent tool refinements reduced the blade actuation pressure to 750 psi. This was successfully confirmed during the test.

The RMOTC test of the 8-1/2" TRACS^{TM} system utilized a 6-1/2" Dyna-Drill F2000S motor with a 1.25 degree bent housing and an 8-1/2" Hughes ATJ-**22** bit. TRACS^{TM} was run directly on top of the Steerable motor. TRACS^{TM} was programmed with six positions ranging from 8-1/2" in the fully opened position to 7-1/4" in the fully retracted position. Commands were sent to the tool by cycling the mud pumps. Two short flow cycles (approximately 30 seconds in duration) was followed by a command flow cycle (approximately 30 per 1/4" position change). The tool confirms its position by sending back a series of pulses. These pulses are easily distinguishable from the MWD mud pulses due to their large amplitude and duration.

The TRACS^{TM} tool went in the hole at 3,319' and drilled to 4,435' in 45 hours. The hole inclination was 30* and the directional objective was to hold angle. The original BHA configuration started to build angle and the TRACS^{TM} blades were expanded to drop angle and bring the hole back on course. Several adjustments were made to both build and drop angle during the course of the well and the hole was kept on course to TD. Only 45' of hole was drilled in the slide-mode when the Muddy formation caused unexpected azimuth changes. The rotary drilling mode allowed more effective hole cleaning. Weight-on-bit was able to be optimized at 30,000 lbs to maintain effective penetration rates. The rotary speed was 65 RPM. The average penetration rate was 24.8 ft/hr. Planned penetration rate was 20 ft/hr. In the 6" lateral, a TRACS tool was not available, and much of the drilling had to be done in the slide mode. Penetration rates in this section averaged only 16.6 ft/hr. In addition, two trips were required for BHA changes.

During the RMOTC test, the TRACS™ tool performed flawlessly. Two trips for a change in BHA were probably saved. The first was when the original BHA tried to build angle immediately after drilling started. The second was while drilling the Muddy sand, when the hole tended to turn to the right. Both situations were handled adequately with adjustments in the stabilizer diameter, saving approximately 12 hours of rig time. The TRACS™ tool was handled with normal equipment and practices on the rig floor. No internal leaks were noted. The MWD operator also monitored the TRACS™ positions and aided the directional driller in making adjustments to the stabilizer positions. Additional technical personnel were not required for its operation, although they were present to observe its performance.

Smith Drilling and Completions' Trackmaster™ Single Trip Sidetracking System

Sidetracking usually involves setting a whipstock and then cutting a window with a series of mills. This is usually accomplished in about four trips if no problems are encountered. Smith Drilling and Completions has developed a system that is capable of accomplishing the above in a single trip.

The bottom of the assembly contains the anchor. Above the anchor is the whipstock. A port in the whipstock houses a hydraulic control line from the milling assembly to the anchor to allow hydraulic setting. The top of the whipstock is attached to the lower mill with a shear bolt. The mill assembly contains three mills. The lower mill is conically shaped. The middle mill is teardrop shaped. The last mill is watermelon shaped for dressing the window. Above the mill assembly is an orienting sub, which is attached to the drill collars.

The assembly is run in the hole to the proper depth, where it is oriented with an MWD aligned with the face of the whipstock. Circulation is established to allow signals from the MWD to be relayed to surface. When the depth and orientation is on target, a flow control switch is activated that closes the circulation ports and allows the circulating Pressure to act on the anchor. The anchor is then set hydraulically by pressuring up the drill string. When the anchor is set, the string is pulled up to shear the milling assembly off of the whipstock. Circulation through the mills is initiated when the milling assembly is sheared off the whipstock and the anchor Other ports are capped and are opened up as their breakaway caps contact the whipstock during the milling process. The window can then be milled without puffing back out of the hole.

With this system, a separate starter mill assembly is norequired to initiate the cut The mill is designed for greater contact area on the whipstock than on the casing, increasing the stress on the casing. The whipstock is made of heattreated steel, which is much harder than the casing.

A mid-ramp accelerator is included which speeds the milling process when the mill is halfway through the casing At this point, the mill tends to cut a core, and milling efficiency is generally lower. The accelerator has a more aggressive angle at this point of the whipstock to speed the milling process.

The mills are made with both crushed and preformed carbide for faster and more consistent milling. The cuttings are broken up efficiently with this combination, and arc then moved up the hole quicker.

The objectives of the RMOTC test were to prove the design features in the field and to test the running procedures for the tool. The ability of the system to accomplish the window milling procedure on one trip was also to be field proven.

At RMOTC, the 9-5/8" Multi-ramp Single Trip Casing Sidetrack System was run into 9-5/8" casing and set at a depth of 729 feet. A window was milled and I I feet of rathole drilled in 7.5 hours with one trip.

The anchor required 3,000 psi to set. The milling assembly was sheared from the whipstock with 28,000 lbs overpull. Milling was accomplished with 3-4,000 lbs; weight on the mill at 90 to 100 RPM. Circulating pressure was 600 psi at 380 gpm. The rotary speed and weight were increased slightly to mill past the center point. The milling operation went as planned.

The hole was then blown dry and downhole video shot of the whipstock, window, and the rathole. A drilling BHA was then run through the window to ensure accessibility. The BHA, with an 8-1/2" bit, full gauge integral blade stabilizer (IBS), a 9 ft pony collar and I I drill collars, was used confirm that a drilling assembly could pass smoothly through the window. The whipstock was then conventionally retrieved for inspection.

The test of the Trackmaster™ Single-Trip Casing Sidetrack System at RMOTC was considered to be a success. Smith Drilling and Completions won the PEI Meritorious

Award for Engineering Innovation for the system and is now marketing it commercially. It provides a cost-saving solution to conventional cased hole sidetracking alternatives.

Halliburton's Bottom Hole Kickoff Assembly

Usually two to three cement plugs are required to be set before a successful kickoff is achieved. Although advancements have been made in plug setting procedures, and tools have been developed to address this problem; plug failures are still common. The bottom hole kickoff assembly developed by Halliburton Energy Services is a significant improvement over previous solutions.

The problem of setting a competent plug is that the cement slurry is usually much more dense than the well fluids. This causes a gravitational instability and the cement tends to migrate downward through the well fluid, causing cement contamination problems. Excess pump and thickening times exacerbate this problem. Once contaminated, the compressive strength curves become severely retarded in both time and amplitude. The gravitational instabilities are worst in wells with 30 to 60 degree inclinations. *This is* a common inclination to deal with in the multilateral arena.

The suggestions in the literature' to prevent these problems include improved hole cleaning, increased slurry volume, and improved slurry design. The slurry should be designed to set up quickly. Sufficient volume should be pumped to prevent contamination. The hole should be scoured well before the slurry is placed. Often the tailpipe movement is the cause of migration.

The design of the bottom hole kickoff assembly takes into account the literature suggestions. The bottom of the tool has a diverter that is used to circulate into the hole to thoroughly clean the hole. An inflatable packer is used to provide a positive seal against contamination and gas migration. An aluminum tailpipe is placed above the packer to circulate the plug into place. It remains in place until it is drilled out to prevent contamination from swabbing. It is centralized by rigid aluminum centralizers to assure good cement distribution. At the top of the tool is a release mechanism to minimize cement swabbing when pulling out of the hole.

The RMOTC test of the bottom hole kickoff assembly was done in a 7-7/8" hole with an inclination of 6.750. Mud weight was 9.2 ppg with a funnel viscosity of 44 sec/qt. Plastic viscosity was 14 cps and the yield point was I I lb/100 ft^2 . There was 25% lost circulation material (LCM) in the mud due to a low pressure fractured reservoir up the hole. The hole was drilled to 5,013' MD. The diverter tool, open hole packer, tail pipe and releasing tool was made up and run in the hole to 4,916. The last 403' were washed with the diverter tool at I I BPM for 5 mins per joint to clean the mud cake from the hole.

The Class G cement slurry was mixed to 17.5 ppg. Three barrels were pumped to inflate the packer. Then a dart was pumped to open the circulating ports for the cement. The

volume of the tailpipe was pumped, followed by a dart to release the drill string from the tail pipe. The pipe was circulated clean and tripped out of the hole.

A bit tagged the top of cement at 4363'. The top of the plug was dressed off to 4500'. A motor with a 2 degree bent sub was used to start the kickoff by time drilling for about 18 hours. Weight on bit was then increased and the assembly rotated to build angle.

The bottom hole kickoff assembly has worked as expected in setting a competent plug. Despite the 8 ppg difference in density between the mud and cement slurry, gravitational instability was prevented by the inflatable packer. The aluminum tail pipe drilled up easily inside the cement Since 25% LCM was required, the shale shaken were being bypassed, and some rubber got through to the mud pumps, causing some plugging. However, the tool performed flawlessly, and the kickoff was achieved on the first try.

IDS/Anadrill's Stacked Multidrain System

In cooperation with RMOTC, Anadrill Schlumberger and Integrated Drilling Services (IDS) recently conducted a field test of the RapidConnect™ system which incorporates an articulated, scaled outlet for multilateral drilling applications. *This* technology is designed to provide an integral, positive seal at the junction between the parent-well casing and the outlet, independent of cement integrity. The prefabricated outlet design will eliminate the need for milling a window in the casing and permit the hanging of a liner packer inside the lateral branch.

Following the directional orientation of the equipment in the hole, the outlet is opened and latched in place using an inflatable packer. After the casing is cemented, the system will accommodate the drilling of a lateral branch through the outlet and permit liner running.

The RapidConnect™ system and all associated orientation/opening equipment is manufactured by Camco Products & Services Company. Smith Drilling and Completions underreamed a section of an existing wellbore to facilitate the placement of the equipment, which is an integral part of the parent well casing string.

Smith Drilling and Completions' Rotary Steerable System Directional wells are more expensive and difficult to drill than vertical wells. Downhole motors and MWD systems have made directional wells economical and predictable. They have also increased the complexity of the downhole equipment and shed some of the time honored practices that has make rotary drilling successful. A static BHA reduces the efficiency of cuttings removal, adversely affecting penetration rates, and increasing the incidence of stuck pipe.

The rotary steerable systems can not only reduce trouble costs, but can provide a more efficient directional drilling system8. Significant amounts of time spent "drilling" with a downhole mud motor is actually spent on orienting the tool face so the proper orientation is achieved, once the weight is

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